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Structural Transformations in Production and Consumption: Long-Run Growth and Income Disparities*

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Abstract

The paper provides a theoretical explanation for the dramatic differences observed in the income growth and distribution across countries and within countries through time. The model we propose provides micro foundations for linking structural change to economic growth. The model formalizes the links between production technology, firm organization, and functional composition of employment on the supply side and the endogenous evolution of income distribution and consumption patterns on the demand side. Wage distribution is the main channel between the organization of firms and the consumption patterns. Firm selectionis the main trigger of capital investment, productivity increase, and cumulative causation growth through demand.

We analyze the effect of different structural conditions via numerical simulations. We find that these conditions have a stunning effect on the long run rate of income growth and distribution. For example, product and demand variety have a jointly positive effect on growth when variety cumulates over time. Large jumps in technological change affect the economy in a very heterogeneous way, depending on the complexity of firm organization; the positive effect of complex organizational structures on growth can be hindered by large earning disparities.

Keywords: Structural change; growth; income distribution; consumption; firm organization; technological change

JEL: O12, J31, L23, D11, O41

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1 Introduction

Since the seminal work of Solow (1957), growth accounting exercises have clearly shown that production factors alone can explain only a limited part of the dramatic growth some countries have experienced in the past two centuries (Maddison, 2003; Hulten, 2009). It is also difficult to explain the dramatic divergence between the growth rates of countries and within country increases in inequality using an accumulation of production factors approach (Denison, 1967; Denison, 1979; Maddison, 1987; Barro, 1991; Durlauf and Quah, 1998). For example, how do we explain the large differences in the recent growth performance of Europe and the U.S.? Or how do we explain the changes in the U.S. labor productivity growth in the last half century, which slowed down from 3.3 percent (1948-1973) to 1.6 percent (1973-1995), rising again to an average 2.6 percent (1995-2007) (U.S. Department of Labor, Bureau of Labor Statistics, 1983; Hulten, 2009)? Clearly, there is no lack of alternative explanations, including changes in the labor market, the ICT 'revolution,' oil shocks, product and process innovations, access to education, national systems of innovation, or even institutions, and so forth.

The main argument of this paper is that many of these candidate explanatory factors operate through, or are an outcome of, the structure of the economy. An economy's structure is defined in terms of its components and their interactions. "Components are not just industrial sectors, but also entities at lower levels of aggregation, such as particular goods or services, and other activities and institutions, such as technologies, types of knowledge, organizational forms etc." (Saviotti and Gaffard, 2008, p.115). We aim to provide a theoretical explanation for the dramatic differences in income growth and distribution as an outcome of the structure of an economy, and its change over time. Although structural change is both a determinant and a consequence of growth (Saviotti and Gaffard, 2008), here we mainly focus on structural conditions as determinants of growth.

Going back to the classical growth accounting framework, changes in an economy's production function (capital deepening and labor input) and outward shifts of the production function (productivity improvements) are not independent of each other. We suggest that both are related to the way in which production is organized (e.g., in the effects of ICT on the division of labor), the composition of output, and the technologies of production. Second, we also argue that those changes are not independent of the structure of demand, defined mainly in terms of wage/income distribution and the consumption patterns of different sectors of the population. Third, we argue that the structural changes on the demand and supply sides are not independent of one another. In sum, we look at the Solow residual as a set of conditions that determine the structure of production and demand, both of which are not independent of accumulation and employment of the the production factors themselves.

To formalize these hypotheses we need a model that provides a micro foundation to the link between structural change and growth. The model we propose specifies the links between production technology, organization, and functional composition of the employment on the supply side and the endogenous evolution of income distribution and consumption patterns on the demand side. In the absence of product innovation, wage distribution is the main channel connecting changes in the organization of firms to changes in consumption patterns. Firm selection, which occurs as a joint outcome of changing consumption patterns and firms' growth and investment dynamics, is the main trigger of current capital investment, productivity increase, and the cumulative causation of growth through demand expansion.

The model we propose is analyzed using numerical simulations. First, we show the relevance of the structural changes in determining the model outcome. We then focus on five main structural parameters characterizing an economy: (i) composition of production, defined as the variance in firms' product mix and proxied by product qualities and prices; (ii) consumption structure, defined as the variance in the emerging mix of consumption patterns in an economy and proxied by the interclass differences in preferences; (iii) complexity of the organization structure defined as the number of tiers of executives necessary to manage a firm, *ceteris paribus*; (iv) wages structure, defined by the wage differences between organizational tiers; and (v) production technology, proxied by the speed at which technical change is embedded in production practice.

These five parameters allow us to put forward the following three conjectures: (i) Product variety, in conjunction with variety in the demand patterns, are accompanied by an expansion of the economy and determine the rate of output growth. (ii) Complex organizational structure and rapid technological change yield a larger output growth by increasing effective demand. For a given rate of productivity growth at the micro level, change in aggregate productivity is strongly affected by the different growth patterns in individual firms that result from their different organizational structures. In effect, an increase in the speed of technological change accelerates aggregate growth and productivity at rates that depend on the pattern of organizational complexity. (iii) Complex organizational structures coupled with large wage disparities are likely to generate a highly unequal society in which household incomes and aggregate output growth are the result of endogenous changes in the demand structure.

Similar attempts to relate growth to the distribution of income via demand–induced innovation are found in a recent stream of macro models (Föllmi and Zweimüller, 2008; Föllmi, 2003; Aoki and Yoshikawa, 2002; Matsuyama, 2002; Falkinger and Zweimüller, 1997). Similarly to these contributions our model is also inspired by the classical works in the post–Keynesian tradition that link growth to structural change (Pasinetti, 1981; Sirquin, 1988; Cornwall and Cornwall, 1994; Kurz and Salvadori, 1998; Cesaratto, Serrano, and Stirati, 2003). We differ from these models mainly in the extensive use of micro foundations, which is closer to the work done, among others, by Arifovic, Bullard, and Duffy (1997), Deissenberg, Van Der Hoog, and Dawid (2008), Dosi, Fagiolo, and Roventini (2010) and some of the models in Dawid and Fagiolo (2008). To model the micro foundations that link the changes in technology, firm's organization, functional distribution of employment, and consumer behavior we follow recent advances in the study of macro economic dynamics that convincingly show the relevance of including into macro models careful consideration of heterogeneous human agents behavior (Akerlof and Shiller, 2009), and "non–routine decision making and unforeseeable changes in the social context within which individuals make decisions" (Frydman and Goldberg, 2007, cited from Phelps' Foreword on page xviii). Our model can be seen as a bridge between the Schumpeterian and structuralist literature and models that look at both economic agents' transaction and "the nature of their interactions with each other and with their environment" (Howitt, 2006, p. 4), as discussed also in Colander, Howitt, Kirman, Leijonhufvud, and Mehrling (2008) and LeBaron and Tesfatsion (2008).

Following existing Schumpeterian growth models (see, among many other contributions, Aghion and Howitt, 1992; Aghion and Howitt, 1998; Aghion, 2002; Acemoglu and Guerrieri, 2008), we consider economies to be composed of a manufacturing sector and an intermediate sector. Unlike some of these models and in line with the micro foundations aimed in this paper we do not abstract from capital accumulation, and limit the analysis to one intermediary sector producing capital goods (see, e.g., Chiaromonte and Dosi, 1993; Silverberg and Verspagen, 2005). In particular, the relation between technical change and demand partially refers to the evolutionary tradition that study the cumulative causation of growth (Verspagen, 1993; Verspagen, 2004; Montobbio, 2002; Llerena and Lorentz, 2004; Lorentz and Savona, 2008; Patriarca and Vona, 2009). The manufacturing sector serves final consumption, while the capital sector provides manufacturing firms with a succession of vintages of capital, each with different abilities to contribute to productivity. Both markets are competitive. We assume persistent disequilibrium and no market clearing due to non–coordinated demand of heterogeneous agents and adaptive *incorrect* expectations (Phelps, 2007). Final consumers select firms from the manufacturing sectors, whereas manufacturing firms, when they invest in capital stock, select among the capital producers. Excess demand and supply result in end of the period production backlogs and inventories. Firms use this information to adjust future production accordingly.

Manufacturing firms produce a good with different quality levels, representing competing product technologies. This allows us to define product variety or structural differences in terms of different sectors that satisfy different consumers, similar to Föllmi (2003), Aoki and Yoshikawa (2002), Falkinger and Zweimüller (1997), and Saviotti and Pyka (2004). To produce outputs, firms use labor and a stock of capital. Labor is the source of variable costs, while capital stock is built through lumpy investments in the succeeding vintages of capital output. Labor productivity depends on capital investment.

Capital sector firms produce capital vintages using only labor. The increase in productivity in new vintages depends on the level of investment in research and development (R&D), which is constrained by the firm's profits. Different regimes determine the speed at which advances in production technology occur.

For both sectors labor includes 'productive' workers on the shop floor, and 'organizational' workers distributed in hierarchies. Firms are defined with respect to their organization structure both in terms of the number of hierarchical tiers of workers and executives and the wage differentials across tiers (Simon, 1957; Lydall, 1959; Waldman, 1984; Abowd, Kramarz, and Margolis, 1999; Prescott, 2003).[1] The lower the number of subordinates each executive can coordinate, the more *complex* is the organization and the 'taller' is the organizational pyramid. The hierarchical structure of wages linked to the organization determines the distribution of earnings across consumers and firm costs (Brown and Medoff, 1989; Criscuolo, 2000; Bottazzi and Grazzi, 2007). Income level and purchasing power of different consumer classes depend also on the minimum wage, which is determined at the macro level by an outward shifting *wage curve* (Blanchflower and Oswald, 2006).

Income distribution, then, is a direct outcome of the industrial and labor structure (Aghion, Caroli, and García-Peñalosa, 1999). We depart from the view that wage distribution strictly depends on labor skills and skill–biased technical change (Tinbergen, 1975), taking on board the more convincing evidence that wages are determined by the composition of production at the macro level (Galbraith, Lu, and Darity, 1999; Galbraith, 1999) and by the organization of production at the micro level (Caroli and Van Reenen, 2001; Prescott, 2003; Atkinson, 2007).

The dual relation between income growth and distribution (Stiglitz, 1969; Atkinson, 1997; Aghion, 2002; Galbraith, Lu, and Darity, 1999; Galbraith, 1999) therefore depends on the way in which economic structure and specialization relate to the organization of production and how they both impact on the wage structure. In fact, demand is often taken to have a prominent role in defining the growth pattern and level (Cowan, Cowan, and Swann, 1997; Aversi, Dosi, Fagiolo, Meacci, and Olivetti, 1999). In the proposed model demand is generated from a number of consumer/income classes which are defined by the wage–tier organizational structure, drawing a one–to–one relation between the structure of consumption and production (Schumpeter, 1934). The composition of each class is defined in terms of consumption preferences with respect to product price and quality. As has been established by interdisciplinary evidence and theories on consumption (Valente, 1999; Swann, 1999; Witt, 2006; Babutsidze, 2007) and satisfying behavior (Shafir, Simonson, and Tversky, 1993; Gigerenzer, 1997), the consumer ranks the goods with respect to their relative position rather than their absolute value using lexicographical preferences. The distribution of consumer preferences over the goods' characteristics defines the demand curve and firms' output shares. As expected, this has an impact on the production structure, the production technology, and each firm's organization.

In the remainder of the paper, we provide a detailed description of the model (2). We use it to analyze and explain the impact of structural conditions on growth and distribution via numerical simulations (3), and we close with a brief discussion and a summary of our contribution (4).

[1] Rosen (1982) develop similar arguments, although less focussed on firm's organization.

2 The model

In a nutshell, the model is structured as follows: an economy has a final good sector with a population of $f \in \{1, 2, ..., F\}$ firms, each producing one good with a specific product technology; a population of consumers pertaining to $z \in \{1, 2, ..., \Lambda_t\}$ *income classes* that differ in their preferences over product technology, i.e. that have lexicographic preferences over the set of firms; a capital sector with a population of $g \in \{1, 2, ..., G\}$ firms that produce and innovate the process technology (capital vintages) used in the manufacturing sector. Firms in both sectors are hierarchically organized in $l \in \{1, 2, ..., \Lambda_t\}$ tiers of workers/managers. Each tier corresponds to a consumer class z. Together with a minimum wage setting at the macro level, the firm's hierarchy defines consumer's wage. Consumers from different classes, with different wages and preferences, close the model, buying from firms with given product technologies.

2.1 Final good sector

2.1.1 Output

Each firm $f \in [1; F]$ produces only one good for the final consumer market. In line with the Lancasterian (Gorman, 1959; Lancaster, 1966b; Lancaster, 1966a) approach to consumer theory, each good is characterized by a quality index (i_2) as well as by a price index (i_1). While price is determined by the firm's variable costs,[2] quality is exogenous. Quality variety across firms is one of the parameters that we investigate in this paper as a structural condition that links supply–side to demand–side structural change. A firm good can thus be represented as:

$$\begin{pmatrix} i_{1,f,t} \\ i_{2,f} \end{pmatrix} \tag{1}$$

Quality and price determine consumer choice across existing producers, as explained in Section 2.3. Given the resulting share of total demand faced by a firm ($Y_{f,t}$), current expected sales Y^e_t are a convex combination of past expectations and the share of demand faced in the previous period:

$$Y^e_{f,t} = a^s Y^e_{f,t-1} + (1 - a^s) Y_{f,t-1} \tag{2}$$

We assume a slow adaptation in sales expectations (a^s) as an outcome of firms' conservative behavior aimed at smoothing short–term cycles.[3]

In order to cover unexpected demand changes, firms maintain a desired level of inventories $\left(\bar{s} Y^e_{f,t}\right)$.[4] Production plans $\left(Q^d_{f,t}\right)$ are then revised to adjust to changes in the

[2] See section on costs and price determination 2.1.3.

[3] See Table 2 for a full list of parameter values.

[4] We assume an inventory/sales ratio which corresponds to the minimum of the observed values (see, e.g., McCarthy and Zakrajšek, 2000; U.S. Census Bureau, 2008), both to avoid level effects that may be linked to the accumulation of inventories and reduce the propagation of business cycles.

expected demand $\left(Y^e_{f,t}\right)$ and existing inventories ($S_{f,t-1}$):

$$Q^d_{f,t} = \max\left\{(1+\bar{s})Y^e_{f,t} - S_{f,t-1}; 0\right\} \tag{3}$$

where inventories meant to work as production buffers adjust in the following way:

$$S_{f,t} = S_{f,t-1} + Q_{f,t} - Y_{f,t} \tag{4}$$

Note that we allow here inventories to be negative, which corresponds to the level of unfulfilled demand or backlog.

Finally, production aims to cover current plans, given the availability of labor $\left(L^1_{f,t-1}\right)$ and capital ($K_{f,t-1}$):

$$Q_{f,t} = \min\left\{Q^d_{f,t}; A_{f,t-1}L^1_{f,t-1}; DK_{f,t-1}\right\} \tag{5}$$

where A_{t-1} is the labor productivity embodied in the capital vintages and D is the fixed capital intensity ratio.[5]

2.1.2 Production factors and organization structure

The production capacity of firms is then determined by the structure of labor and capital stock. Labor productivity depends on firms' investment in capital (see below) and on the R&D of capital suppliers (Section 2.2.2), which, in turn, reflects the demand of final good firms. The labor market is assumed to be inertial but unconstrained, while available capital is limited by its suppliers' production capacity (see Section 2.2.1).[6]

We model the structure of firms' labor force after the hierarchical representation of firms' organization in tiers in Simon (1957). First, given the level of output, firms hire productive labor $L^1_{f,t}$ according to labor productivity $A_{f,t-1}$ and an unused labor capacity (u^l) to insure against an unexpected increase in demand:

$$L^1_{f,t} = \epsilon L^1_{f,t-1} + (1-\epsilon)\left[\left(1+u^l\right)\frac{1}{A_{f,t-1}} min\{Q^d_{f,t}; BK_{f,t-1}\}\right] \tag{6}$$

The inertial factor ϵ_L mimicks labor market rigidities. Second, firms then need to hire 'executives' to manage the lower tier of subordinates: every batch of ν productive workers requires one executive; each batch of ν second–tier executive requires a third–level executive, and so on. The number of workers in each tier, given $L^1_{f,t}$, is thus

$$\begin{aligned} L^2_{f,t} &= L^1_{f,t}\nu^{-1} \\ &\vdots \\ L^z_{f,t} &= L^1_{f,t}\nu^{(1-z)} \\ &\vdots \\ L^{\Lambda_f}_{f,t} &= L^1_{f,t}\nu^{\left(1-\Lambda_f\right)} \end{aligned} \tag{7}$$

[5]Our assumption of fixed capital intensity is sustained by numerous empirical evidences, starting with Kaldor (1957). The equation insures that capital will be accumulated is in accordance with this fixed ratio.

[6]We do not assume an infinitely elastic labor supply curve as shown in the labor market dynamics described in Ciarli, Lorentz, Savona, and Valente (2010).

where Λ_f is the total number of tiers required to manage firm f. Consequently, the total number of workers is

$$L_{f,t} = \sum_{z=1}^{\Lambda_f} L_{f,t}^z = L_{f,t}^1 \sum_{z=1}^{\Lambda_f} \nu^{1-z} \tag{8}$$

Note that the constraint on production due to labor is determined by first–tier workers and their productivity only. The managers are required to organize production.

Following Amendola and Gaffard (1998) and Llerena and Lorentz (2004), capital goods constitute the basis for the firm's production capacity. The accumulation of capital is a precondition for any production activity, constraining the actual production level and affecting the efficiency of the labor force. The capital stock of a firm, where V_f indicates the number of capital vintages acquired, $k_{h,f}$ and τ_h the amount of capital and date of purchase of vintage h, respectively, is computed as:

$$K_{f,t} = \sum_{h=1}^{V_f} k_{h,f}(1-\delta)^{t-\tau_h} \tag{9}$$

where δ is the depreciation rate. The level of productivity embodied in the capital stock is computed as the average productivity across all vintages available:

$$A_{f,t} = \sum_{h=1}^{V_f} \frac{k_{h,f}(1-\delta)^{t-\tau_h}}{K_{f,t}} a_{g,\tau_h} \tag{10}$$

where a_{g,τ_h} is the productivity embodied in the h vintage.

Indicating as u the required percentage of unused stock, the desired amount of new capital (expressed in production units) then is:

$$k_{f,t}^e = (1+u)\frac{Y_{f,t}^e}{B} - K_{f,t-1} \tag{11}$$

If $k_{f,t}^e$ is positive, the firm selects one of the capital producers $g \in \{1; ...; G\}$ with a given probability and places an order for the desired stock:

$$k_{g,f,t}^d = k_{f,t}^e \tag{12}$$

The probability to pick a producer g increases with its embodied productivity ($a_{g,t-1}$) and decreases with its price ($p_{g,t-1}$) and the waiting time. The actual delivery of the capital may, in fact, take place after one or more time steps, depending on the capital supplier's production capacity. While waiting for the ordered capital, the final good firm f has to delay any new capital investments. Once the order is received, firm f introduces the new capital vintage in its capital stock:

$$k_{h+1,f} = k_{g,f,t}^d \tag{13}$$

2.1.3 Production costs, price determination, and profits

Production costs reflect the sole variable production factor, i.e., labor. The cost of labor depends on the minimum wage and on firms' organizational structure. The minimum wage is endogenously determined at the macro level (see Section 2.3.1). To model the firm–specific wage structure, we refer to the original work of Simon (1957) and Lydall (1959), and further extensions of this literature (Waldman, 1984; Abowd, Kramarz, and Margolis, 1999; Prescott, 2003; Rosen, 1981; Rosen, 1982). According to this literature, the complexity of the hierarchical organization of the firm, defined as the number of executive tiers for a given number of shop floor workers, exponentially affects the structure of pay. In our model first–tier wages are set by firms as a fixed multiple ω of the minimum wage w^m_{t-1}:

$$w^1_{f,t} = \omega w^m_{t-1} \tag{14}$$

As we move upstream in the organizational hierarchy, the wage increases by a fixed multiplier b, determining the skewness in the wage distribution:

$$\begin{aligned} w^2_{f,t} &= b w^1_{f,t} \\ w^3_{f,t} &= b w^2_{f,t} = b^2 w^1_{f,t} \\ &\vdots \\ w^{\Lambda_f}_t &= b^{\Lambda_f - 1} w^1_t. \end{aligned} \tag{15}$$

Unit production costs thus correspond to the wages bill of the firm divided by its production level (Q_t). Note that the tier–wage structure of variable costs implies diseconomies of scale in the short run[7] in accordance with the evidence that labor cost is higher for large firms (Idson and Oi, 1999; Criscuolo, 2000; Bottazzi and Grazzi, 2007):

$$c_t = \frac{1}{A_{f,t-1}} \sum_{l=1}^{\Lambda_f} w^l_t \frac{L^l_{f,t-1}}{L_{f,t-1}} \tag{16}$$

The price is set as a markup on unit costs:[8]

$$p_t = (1 + \bar{\mu}) c_t \tag{17}$$

with profits (π_t) resulting as the difference between the value of sales and the variable costs of production:

$$\pi_t = p_{t-1} Y_t - \sum_{l=1}^{\Lambda} w^l_t L^l_t \tag{18}$$

As noted by Atkinson (2007), the exponential structure of wage–tier increase is not sufficient to explain the skewness in earnings distribution. On top of their wages, executives are paid wage premia ψ^l_t that we interpret as profit shares. Assuming that firms invest in

[7] In the long run, productivity gains through the accumulation of capital vintages may overcome these diseconomies of scale, generating dynamic increasing returns.

[8] An assumption supported by empirical evidence dating back to Hall and Hitch (1939) and, more recently, to Blinder (1991) and Hall, Walsh, and Yates (1997).

capital whenever they face a production constraint, cumulated profits $\Pi_t = \sum^t \pi - R^I_{t-1}$ are eroded by the capital expenditure $R^I_t = \sum_{\tau=0}^{t} p^k_{\tau-1} k_\tau$, where $p^k_{\tau-1} k_\tau$ are the resources used for capital vintages τ completed in time t. The residual amount of cumulated profits $R^D_t = max\{0; \Pi_t - R^I_t - \sum_{\tau=1}^{t-1} R^D_\tau\}$ is then allocated to the payment of bonuses and dividends:

$$\psi^l_t = \frac{w^l_t}{\sum_{l=2}^{\Lambda} w^l_t} R^D_t \tag{19}$$

Substituting, in 19, the wage structure defined in Equation 15, the overall earnings per tier of worker are:

$$w^l_t + \psi^l_t = \begin{cases} \omega w^m_{t-1} \text{ for } l = 1 \\ \\ \omega w^m_{t-1} b^{l-1} + \frac{b^{l-1}}{\sum_{l=2}^{\Lambda} b^{l-1}} R^D_t \text{ for } l \in \{2; ...; \Lambda\} \end{cases} \tag{20}$$

2.2 Capital sector

2.2.1 Production process

Capital goods are produced by capital producers $g \in [1; ...; G]$ in the corresponding sector. Each capital good is characterized by its vintage τ, embodied productivity level $a_{g,\tau}$, and price $\left(p^k_{g,t}\right)$. Each firm produces one vintage of capital at a time.

The embodied productivity, the price of the good, and the production queue $(U_{g,t-1})$ of the capital producer determine the choice (selection) of final good firms in each time period. This, in turn, determines the demand for capital producers. The production plan of each firm aims to meet current clients' orders $(k^d_{g,f,t})$ as well as the remaining unmet orders from previous periods $(U_{g,t-1})$:

$$K^d_{g,t} = \sum_{f=1}^{F} k^d_{g,f,t} + U_{g,t-1} \tag{21}$$

As for the final good firms, the output is constrained by the firm's production capacity. For simplicity, machinery firms require only labor, and their production capacity $(A^k L^1_{g,t-1})$ depends on their workforce $(L^1_{g,t-1})$ and a fixed level of productivity (A^k). The output quantity is given by:

$$Q_{g,t} = min\left\{K^d_{g,t}; A^k L^1_{g,t-1}\right\} \tag{22}$$

In line with empirical evidence (see, e.g., Doms and Dunne, 1998; Cooper and Haltiwanger, 2006), we assume that the production of capital is just–in–time, with no expectation formation or accumulation of inventories of unsold capital. The capital orders are produced according to a 'first in, first out' rule. The remaining unmet orders $U_{g,t-1}$ are thus produced before the new ones. The changes in the level of these uncovered orders depend on the current production capacity $(A^k L^1_{g,t-1})$ and the level of demand $(K^d_{g,t})$:

$$U_{g,t} = max\left\{K^d_{g,t} - A^k L^1_{g,t-1}; 0\right\} \tag{23}$$

Labor input is modeled in the same way as in the final good sector. First, given the level of output, capital good firms hire productive labor $L^1_{g,t}$ according to labor productivity $\left(A^k\right)$ and an unused labor capacity (u^m):

$$L^1_{g,t} = \epsilon_M L^1_{g,t-1} + (1 - \epsilon_M) \left[(1 + u^m) \frac{K^d_{g,t}}{A^k} \right] \tag{24}$$

where the convex combination with the previous period labor given by ϵ_M mimicks labor market rigidities. Second, machinery firms hire one executive for every batch of ν subordinates to organize their work. The total number of workers can then be expressed as:

$$L_{g,t} = L^1_{g,t} + L^2_{g,t} + ... + L^{\Lambda_g}_{g,t} = \sum_{l=1}^{\Lambda_g} L^1_{g,t} \nu^{1-l} \tag{25}$$

where ν is equal for final good and machinery firms.

2.2.2 Innovation in capital vintages

As it is usually the case in Schumpeterian growth models (Aghion and Howitt, 1998; Silverberg and Verspagen, 2005) innovation follows a stochastic process with some probability distribution and depends on the resources invested. The productivity embodied in the capital goods is the result of firms' R&D activity. Capital good firms invest in R&D to improve or maintain their market share. Here the overall R&D process accounts for the uncertainty of innovation results — which is not always successful — is in line with Nelson and Winter (1982) and most of the evolutionary growth models developed since, and follows the model in Llerena and Lorentz (2004). R&D investments occur as an increase in the number of research engineers $(L^E_{g,t})$ employed by the firm. The outcome of research activity is stochastic, and the probability of succeeding in innovation depends on the number of engineers employed:

$$P_{g,t} = 1 - e^{-\zeta L^E_{g,t-1}} \tag{26}$$

where the number of engineers employed depends on a maximum share ρ of the firm's cumulated profits $(\Pi_{g,t})$, constrained by a maximum ratio ν^E of the number of productive workers $(L^1_{g,t})$:

$$L^E_{g,t} = min\left\{ \nu^E L^1_{g,t}; max\left\{ \rho^k \Pi_{g,t}; 0 \right\} \right\} \tag{27}$$

If the R&D activity is successful, the productivity of the new capital vintage is a random process that depends on the productivity achieved in past R&D efforts, in line with the concept of 'local search' (Nelson and Winter, 1982):

$$a_{g,\tau} = a_{g,\tau-1} \left(1 + max\{\varepsilon_{g,t}; 0\}\right) \tag{28}$$

$$\varepsilon_{g,t} \sim N(0; \sigma^a) \tag{29}$$

In other words, the advances in the vintage's productivity, which are transferred to labor productivity of the final good firms when they purchase the new capital, are bigger the larger the variance of the stochastic process of innovation, σ^a. The new vintage is subsequently produced by the machinery firm from the next period until it is replaced by the production of another vintage with higher embedded productivity.

2.2.3 Production costs, price, and profits

Symmetrically to the final good sector, prices of capital goods $\left(p^k_{g,t}\right)$ are set according to a markup rule (μ^k) on unit production costs. In the case of machinery firms, unit production costs include labor costs as well as R&D costs (engineers):

$$p^k_{g,t} = (1+\mu^k)\left(\frac{1}{A^k}\sum_{l=1}^{\lambda_g} w^l_{g,t}\frac{L^l_{g,t-1}}{L_{g,t-1}} + \frac{w^E_t L^E_t}{A^k L^1_{g,t-1}}\right) \tag{30}$$

The wage structure (labor costs) also corresponds to final good firms: as we move upstream in the hierarchy, the wage increases by a given multiplier. We assume no hierarchy for engineers' wages $\left(w^E_{g,t}\right)$, which are paid as a multiple of the minimum wage $\left(w^m_{t-1}\right)$.

$$w^l_{g,t} = \omega^k w^m_{t-1} b^{l-1} \tag{31}$$

$$w^E_{g,t} = \omega^E w^m_{t-1} \tag{32}$$

The profits $\pi_{g,t}$ are cumulated $(\Pi_{g,t})$ either to be redistributed as dividends and bonuses $(R^D_{g,t})$ or for investments in engineers $(w^E_{g,t}L^E_{g,t})$:

$$\pi_{g,t} = p^k_t Y^k_t - \sum_{l=1}^{\Lambda_g}\omega^k w^m_{t-1} L^1_{g,t-1}\left(\frac{b}{\nu}\right)^{l-1} - w^E_t L^E_t \tag{33}$$

$$\Pi_{g,t} = \sum_{\tau=1}^{t}\pi_{g,t} - \sum_{\tau=1}^{t} w^E_{g,\tau-1}L^E_{g,\tau-1} - \sum_{\tau=1}^{t} R^D_{g,\tau-1} \tag{34}$$

$$R^D_{g,t} = (1-\rho)\Pi_{g,t-1} \tag{35}$$

The bonus distribution scheme is similar to the one for final good firms:

$$\psi^l_{g,t} = \frac{w^l_{g,t}}{\sum_{l=2}^{\Lambda_g} w^l_{g,t}} R^D_{g,t} \ \forall l \in \{2; ...; \Lambda_g\} \tag{36}$$

2.3 Demand

Demand is generated by firms' employees who use their wages and distributed profits to buy products from the firms in the final good sectors. We assume that a consumption class z can be defined as the class of workers of a given tier l of the firm's organizational hierarchy. As social and income factors identify the different classes, consumption patterns also differ across consumption classes. Therefore, the structure of the consumption classes determines the structure of demand, which has an impact on firm selection, thus changing the structure of supply.

2.3.1 Income distribution and class consumption level

The income available for each class corresponds to a share of the total wages (W_t^w) and profit shares (W_t^ψ):

$$W_{z,t} = \chi_{z,t}^w W^w + \chi_{z,t}^\psi W^\psi \tag{37}$$

The total income generated by wages corresponds to the sum of each firm's wage bill in both final good and machinery sectors and is a function of the minimum wage as well as of the hierarchical structure of the firms:

$$W_t^w = w_{t-1}^m \left[\omega \sum_{f=1}^{F} L_{f,t-1}^1 \sum_{l=1}^{\Lambda_f} \left(\frac{b}{\nu}\right)^{l-1} + \sum_{g=1}^{G} L_{g,t-1}^1 \left(\omega^k \sum_{l=1}^{\Lambda_g} \left(\frac{b}{\nu}\right)^{l-1} + \frac{\omega^E}{\nu^E} \right) \right] \tag{38}$$

The minimum wage (w^m) is negotiated at the macroeconomic level. We assume the negotiation to be linked to three main macroeconomic dynamics: (i) labor productivity growth to maintain the pace of labor value contribution; (ii) consumer prices to insure a long–run stability of purchasing power; and (iii) employment to keep track of labor market dynamics (efficiency wages, corporatism, or bargaining). The formal representation of the minimum wage boils down to a wage curve, a well–established empirical relation (Blanchflower and Oswald, 2006; Nijkamp and Poot, 2005), with outward shifts caused by increases in aggregate productivity and prices. Assuming unconstrained population growth, we derive unemployment from a Beveridge curve with the rate of vacancies endogenously determined by firms' demand of new labor (Yashiv, 2007; Nickell, Nunziata, Ochel, and Quintini, 2002; Börsch-Supan, 1991). In order to avoid short–run fluctuations, we consider moving averages of productivity and prices. A formal representation of the macro dynamics is left out in this paper for the sake of readability; it can be found in Ciarli, Lorentz, Savona, and Valente (2010).

The share of wage income of consumer class z is computed as the ratio between the total wage income of tier $l = z$ for both final good ($f \in [1; ..; F]$) and machinery firms ($g \in [1; ..; G]$) and can be rewritten as:

$$\chi_{z,t}^w = w_{t-1}^m \frac{\omega \sum_{f=1}^{F} L_{f,t-1}^1 + \omega^k \sum_{g=1}^{G} L_{g,t-1}^1}{W_t^w} \left(\frac{b}{\nu}\right)^{z-1} \quad | \; l = z \tag{39}$$

The second component of consumers' income corresponds to the dividends distributed by both final good and machinery firms, denoted by $R_{f,t-1}^D$ and $R_{g,t-1}^D$, respectively:

$$W_t^\psi = \sum_{f=1}^{F} R_{f,t-1}^D + \sum_{g=1}^{G} R_{g,t-1}^D \tag{40}$$

The share of profits redistributed to a given consumer class z, given the tier level profit distribution described in equations 20 and 36, is computed as:

$$\chi_{z,t}^\psi = \left[\sum_{f=1}^{F} \frac{R_{f,t}^D}{\sum_{l=2}^{\Lambda_f} b^{l-1}} + \sum_{g=1}^{G} \frac{R_{g,t}^D}{\sum_{l=2}^{\Lambda_g} b^{l-1}} \right] \frac{b^{z-1}}{W_t^\psi} \quad | \; l = z \tag{41}$$

Combining equations 37 to 41, we can derive the total income available for a consumer class z. This is a function of the level of demand faced by firms, reflected in the number of the firm's first– tier workers, the wage and hierarchical structure, the level of dividends—all of which are defined by a set of fixed of fixed parameters (b,ν,ω and ω^K), and the minimum wage. Total income per class is formally defined as:

$$W_{z,t} = w^m_{t-1} \left[\omega \sum_{f=1}^{F} L^1_{f,t-1} + \omega^k \sum_{g=1}^{G} L^1_{g,t-1} \right] \left(\frac{b}{\nu} \right)^{z-1} + \left[\sum_{f=1}^{F} \frac{R^D_{f,t}}{\sum_{l=2}^{\Lambda_f} b^{l-1}} + \sum_{g=1}^{G} \frac{R^D_{g,t}}{\sum_{l=2}^{\Lambda_g} b^{l-1}} \right] b^{z-1} \tag{42}$$

We apply the widely accepted hypothesis that consumer behavior is driven by long–term expenditure capacity. There exists a momentum in consumers' level of expenses ($C_{z,t}$) that is only partly affected by short–term fluctuations in available income ($W_{z,t}$). In each period the consumed income is thus a linear combination of past consumption and current income:[9]

$$C_{z,t} = \gamma C_{z,t-1} + (1-\gamma) W_{z,t} \tag{43}$$

2.4 Consumer behavior and firms' demand

The consumer's choice of the good and the related selection of firms close the model by allocating the demand to the final good firms. Consumers–workers classes $z \in [0; \Lambda]$ are divided into $h_{z,t} \in [1; H_z]$ consumer *samples*, each of which undergoes a consumption routine (i.e., a purchase) with symmetric random variations. The amount consumed by each consumer sample h_z is given by the ratio between the total amount of workers in a class of workers and the fixed number of samples L^z/H_z. Therefore, for a small number of consumers, the sample represents a single individual consumption routine. As the number of consumers increases, the sample represents the consumption routine of a group of individuals (a household or a neighborhood). The disposable income of a consumer sample $h_{z,t}$ is given by $\frac{C_{z,t}}{H_z}$

The purchasing behavior is inspired by the literature on experimental psychology and refers to some of the empirically observed properties in this literature (Shafir, Simonson, and Tversky, 1993; Gigerenzer, 1997; Gigerenzer and Selten, 2001). We implement an algorithm which is based on lexicographical preferences, as referred to in the economic literature. Once the available products have been ordered according to their quality and price ($i_{m,f}, m = [1, 2]$), the consumer is indifferent between products that are equivalent to the best product in the market, on the basis of the two characteristics (e.g., lowest price and highest quality). Therefore, consumers' preferences across classes are represented by a 'tolerance level' $\upsilon_{z,m} \in (0, 1]$ that measures the maximum shortfall in the value of each characteristic $i_{m,f}$ with respect to the best product offered across all firms. In other

[9] The savings of a consumer class in period t are the result of nonconsumed income due to consumption smoothing and/or the unavailability of goods to satisfy consumer needs. We simplify the model by assuming that these savings are used to smooth the effect of income reduction to fit equation 43 and not to finance firm investments that rely only on firm profits.

words, consumers' preferences reflect their subjective evaluation of the substitutability of goods. A very high tolerance — low $\upsilon_{z,m}$ — means that a consumer sample is almost indifferent between trademarks (firms), while a very low tolerance means that a consumer sample purchases only from the firm producing the relatively maximum value for a given characteristic m.

More formally, for each consumer sample h_z within each class, the consumption algorithm can be described as follows:

1. The consumer perceives the value $\tilde{i}_{m,f} \sim N\left(i_{m,f}, \varsigma \cdot i_{m,f}\right)$ for both price $(i_{1,f,t})$ and quality $(i_{2,f})$ across all firms f with an observational error with variance $\varsigma \cdot i_{m,f}$.[10]

2. The consumer shortlists a subset of firms $\hat{f} \in \hat{F}_{h,z}$ that satisfy $\tilde{i}_{\tilde{m},f} > \upsilon_{z,\tilde{m}} \cdot \bar{\tilde{i}}_{\tilde{m}}$, $\forall m$, where $\upsilon_{z,\tilde{m}} \in (0,1]$ is the tolerance level and $\bar{i}_{\tilde{m}}$ the value of the best product:

   - if $\hat{F}_{h,z} = \{1\}$ the consumer sample spends all income buying from firm $\hat{f}$ with the highest quality and the lowest price;
   - if $\hat{F}_{h,z} = \{a > 1\}$ the consumption $\frac{C_{z,t}}{H_z}$ is equally shared among selected firms.

The demand for a single firm in time t closes the model, allowing each firm to determine its future expected sales Y^e_{t+1}:

$$Y_t = \sum_{1}^{Z} \sum_{1}^{\hat{H}_z} \frac{1}{\hat{F}_{h,z}} \frac{C_{z,t}}{H_z} \tag{44}$$

where $\hat{H}_{z,n}$ is the number of consumer samples in class z that has selected the firm.

3 Simulation results: Structural differences, growth, and income inequality

In this section, we analyze the effect of exogenous structural conditions on growth and income distribution. In particular, we focus on the effect of the following structural parameters:

$i_{2,f}$ production structure: different levels of product variety

$\upsilon_{z,2}$ consumption structure: different levels of consumer heterogeneity

ν organization structure: different levels of firms' organization complexity. The lower ν, the higher the number of layers in a firm, *ceteris paribus.*

[10] The random discrepancy with respect to the real value allows to relax the assumption that a workers' class perfectly maps the preferences of a consumption class and introduces some variety into consumption patterns. There is ample evidence of imitative behavior across income classes.

σ^a production technology: different levels of technological capacity. The higher σ^a, the higher final good firms' productivity via (i) an increase in the heterogeneity of productivity across firms and (ii) an increase in the productivity gains through capital investments.

b wage structure: wage differentials. The larger b, the higher the labor cost and the more unequal the income distribution

In order to study the interaction of different structural conditions, we analyze the joint effects of product variety and consumption patterns (Section 3.2), of the organization structure and the product technology (Section 3.3), and of the organization and wage structure (Section 3.4). Before, we provide a summary of the long–run pattern obtained when we run numerical simulations of the model with basic initial values to single out the main determinants of growth and distribution (Section 3.1). A full analysis of the aggregate behavior and its microeconomic determinants is found in Ciarli, Lorentz, Savona, and Valente (2010). A presentation of the parametrization of the model as well as a detailed discussion analysis of the model stationarity and sensitivity to different random seeds can be found in Appendix A.

3.1 General patterns of growth and income inequality

The numerical simulations reproduce a growth pattern of GDP similar to what we find in Maddison's empirical work on the long–run growth of Western Europe and its 'offshoots' (e.g. Maddison, 2003; Hulten, 2009). We can easily distinguish a long period of stable but limited growth (reproduced in scale in box (b)), which we call *demand*–led, from the takeoff followed by exponential growth, which we call *Kaldorian*. In both periods growth endogenously emerges from the model. The *demand*–led growth spurs from an initial investment of firms and a recursive mechanism of increase in the number of workers (population), a demand for final consumption, income, firm size, and demand for labor. During this first period investment occurs at the rate of capital depreciation and population growth.

The second stage of exponential growth is a story of market concentration and sudden increase in capital investment by the few firms that start leading the market. The large capital investment induces large jumps in the aggregate productivity, which ignite a cumulative causation process of the Kaldorian type (Kaldor, 1966): price reduction, increased profits, increase in final consumption demand, sustained capital investment, and R&D in capital vintages, with increasing productivity embedded in the capital that sustains the exponential pattern.

[Figure 1 about here.]

At first glance, the two phases of growth patterns (i.e., the *demand* and *Kaldorian*) differ in terms of the R&D expenditure in the capital sector, driving technological innovation and the overall 'size' of the economy. But what ultimately drives these results are the structural conditions that we have imposed in the model.

First, the *organization of production* — number of tiers — is what causes price dispersion across firms, generates wage classes with a direct impact on income distribution. Second, the different consumption classes and the related *wage structure* have different consumption patterns. Third, the variety in the *composition of production* in terms of cost differences allows consumers to select among different goods with different prices. Fourth, the heterogeneity of *consumption patterns* that emerges across consumer classes is the crucial determinant of firm selection when firms follow different growth patterns. Selection, in turn, generates an oligopolistic competition, which is characterized by higher profits concentrated in few firms. It is this concentration of demand and profits that induces a large investment by a small number of firms, requiring new capital vintages and thus inducing high R&D investments in the capital sector. This kicks off the Kaldorian phase of growth. The concentration of production on a reduced number of firms also affects the distribution of income.

3.2 Composition of production and consumption patterns

It is a well–established empirical finding that growth is accompanied by changes in the composition of production. This occurs in terms of both sectoral composition (e.g., Sirquin, 1988; Maddison, 2001; Dosi, Freeman, and Fabiani, 1994; Prebish, 1950) and an increase in product variety and quality differentiation (Saviotti, 1996). Product differentiation is accompanied by a change in consumer preferences and consumption patterns (Maddison, 2001), which become more heterogeneous as a result of the increased variety of production and income classes.

With this first set of simulations, we analyze the effect of the good's quality variety across firms and of different distributions of preferences across consumer classes. We vary the value of the standard deviation of product quality distribution across firms ($s.d.\ i_2$) to analyze the *effect of an increased product heterogeneity.* We also assume that a higher quality level (with respect to the average level across firms) is related to a proportionally higher markup. On the demand side, we vary the heterogeneity in consumer choice. We assume the tolerance for quality is maximum for consumers in the class of first–tier workers (low υ_2) and minimum for the highest tier of managers (high υ_2), decreasing for classes in between. The opposite occurs for the tolerance with respect to price i_1. More generally, the tolerance level is bounded between a minimum level υ_{min} and a maximum level υ_{max}. We modify the difference between these two levels ($\upsilon_{max} - \upsilon_{min}$) to analyze the *effect of an increased consumer heterogeneity.*[11]

As mentioned above and discussed in Ciarli, Lorentz, Savona, and Valente (2010), firm

[11] We use the distance between the minimum and the maximum tolerance level because the standard deviation is endogenous to the model and depends on the growth pattern (and the generation of income classes). The distance allows to compare on a fixed set of possible outcomes the parameters' space for high and low growth.

selection is one of the main conditions for economic takeoff as well as for the increase in consumers' inequality and wealth. Both sets of parameters analyzed here — on product and preferences heterogeneity — have a direct impact on the initial selection of firms. In Figure 2 we show the average level of the inverse Herfindahl Index (HI) across the 2,000 time periods of the numerical simulations.[12] By construction, the market selection increases sharply for high levels of heterogeneity among both consumers and goods offered.

[Figure 2 about here.]

Figure 2 shows economies with a very heterogeneous initial composition of production and of *potential* consumption preferences,[13] which exhibit high market concentration from the beginning of the growth process and throughout the simulation steps. Instead, economies that start with large *potential* initial differences in consumer preferences but low product variety become highly concentrated through time (the decreasing HI that characterizes the west corner of the figure). In this second case, selection occurs as a dynamic process as the economy evolves through price differentiation — linked to initial quality differences as well as growth of new consumer classes and changes in the organization.

When we turn to the effect of the composition of production and demand on economic growth, the numerical simulations of our model only partially endorse the proposition that higher variety (across both goods and consumers) is linked to faster GDP growth (Figure 3). The figure shows two main results: (*i*) a high *initial* variety in the quality of goods produced induces a low growth when goods are substitutes; (*ii*) the heterogeneity between consumer preferences has an effect on growth only when it is very large and is combined with an *initially* low variety in the quality of goods.

[Figure 3 about here.]

In other words, too large a difference between products from the beginning does not allow a takeoff of the economy. In the initial period the aggregate demand is, in fact, too low to generate an investment in new capital by firms. Therefore, firm selection simply reduces the number of vacancies, maintaining a low level of demand (see also results on the number of workers in Figure 15 (a) in Appendix B). Without the demand effect, the cumulative process never gets started, and although the economy experiences an endogenous growth, this is the lower, the higher the initial market concentration. This result is also obvious when the level of population is compared with the aggregate productivity in Figure 15 (b) in Appendix B. For medium to high levels of product heterogeneity, even with a very low number of workers hired, the aggregate productivity remains at very low levels.

To sum up, product variety has to develop through time after the economy has already undergone a growth in production and demand, and has to be accompanied by an emerging

[12]This is HI $= \frac{1}{\sum_{f=1}^{F} s_f} \in [1; F]$, where s is the firm's market share and F the total number of firms.

[13]Recall that, in order for consumer heterogeneity to emerge, new classes need to emerge as a consequence of firms' growth.

differentiation among consumers. Both demand and supply side effects are at work here, but they both require an initial boost in GDP growth. This has to be sufficiently high to turn firm selection into a positive effect for sustained growth. Otherwise, firm selection puts a ceiling on the level of the GDP reached by the economy.

The effect of supply and demand heterogeneity on income inequality is nonlinear (Figure 4): the economy experiences the highest level of inequality in the presence of large initial product heterogeneity and very low GDP. Inequality increases again for very large levels of GDP associated with low initial variety. The heterogeneity of preferences across consumer classes has very little effect.

[Figure 4 about here.]

In both cases of high and low GDP, the inequality is due mainly to the income generated by profit shares (Figure 16 (b) in Appendix B). In particular, we can distinguish two main opposite scenarios: a stagnant and highly unequal economy, on the one hand, and a virtuous, less unequal, growing economy, on the other. In the first case of high *initial* product heterogeneity, a small population enjoys a high average income (Figure 16 (a) in Appendix B) generated through non–invested profits unequally distributed. In the second case of low *initial* product heterogeneity and high (potential) difference in preferences, a large population enjoys a relatively high average income. Given the lower level of inequality, the population is definitely better off in the second scenario.

The bottom line of these results is that product variety has a positive effect when it is generated through a development process and in the presence of *evolving* consumer preferences. Otherwise, it generates no structural change *per se*.

3.3 Organization and production technology

We proceed to analyze the joint effect of production technology (σ^a) and organizational structure (ν). Production technology refers to the capital structure of firms, while the organizational structure reflects the hierarchical structure of labor (i.e., the steepness of the pyramid).

At the firm level, the two parameters have opposite effects. A higher number of layers (low ν), *ceteris paribus*, increase the number of workers and the production costs and reduce the firm's productivity. A wider distribution of the R&D outcome (high σ^a) increases productivity as a result of the investment in new vintages, reducing the number of workers required for the same level of output.

At the industry level, larger potential productivity gains should lead the most efficient firm to grow and dominate the market as a result of the cumulative nature of productivity gains. Nonetheless, a trade–off exists between size and production costs.

Finally, at the macro level both structural parameters should positively affect growth via effective demand: (i) a higher number of layers increase the consumer classes and the number of consumers, while (ii) productivity gains reduce prices. The two structural parameters are expected to increase inequality as well: (i) a higher number of tiers generate a higher dispersion in income distribution by construction; (ii) higher productivity allows for higher profits to benefit the higher tiers of workers; finally, (iii) higher productivity may raise minimum wages, increasing the overall income available and reinforcing the two previous mechanisms through a higher effective demand — triggering an increase in the size of the firms, in the number of layers, and in productivity, due to higher investments.

Figure 5 confirms the expectations on economic growth. It shows the Log of the GDP levels at constant prices after 2,000 simulation steps for various values of the structural parameters. An increase in σ^a positively affects GDP, while an increase in ν — reducing the number of layers, *ceteris paribus* — negatively affects GDP.

[Figure 5 about here.]

The income inequality, though, exhibits a nonlinear pattern. Figure 6 presents the average Atkinson index over 2,000 simulation steps. As expected, for a given σ^a an increase in the tier multiplier (ν) implies a lower level of inequality due to a slower increase in the number of organizational layers for an equal increase in firm size. The relation is reverted for large values of ν: as the organizational structure flattens,the pace of GDP growth is very low and inequality rises again. As discussed for the previous results (Section 3.2), the economy is in a state of very low consumer differentiation and low demand, which does not induce firm selection and the demand trigger for the cumulative causation to occur. Therefore, the very low investment in capital does not ignite any productivity change, and profits are unproductively shared with higher–tier workers.

[Figure 6 about here.]

Conversely, a higher spread of productivity gains (σ^a) generates a higher income inequality, but for the case of the two lower values of ν. In both these cases, income inequality reaches a peak for average values of productivity gains spread ($\sigma^a \approx 0.08$).

The nonlinearity of inequality is explained by the relation between investment, growth, profit distribution, and demand. First, we note that productivity presents a pattern very similar to the Atkinson index (Figure 7). Second, at the firm level the hierarchical structure reduces the firm's efficiency, limiting the effect of productivity gains. In other words, productivity gains tend to erode: high values of σ^a mean that the lower ν (i.e., the larger the number of layers, *ceteris paribus*), the lower is aggregate productivity (see Figure 7). This is confirmed by investigating the employment dynamics (see Figure 17 in Appendix B). Third, large productivity changes (for values of $\sigma^a > 0.08$) sustain a very strong economic growth, which is accompanied and spurred by large increases in population (demand). Those increases keep firms under pressure, requiring large capital investments that reduce the opportunity to share profits. The peak in aggregate productivity thus explains the peak in the Atkinson index by a peak in profit levels that only benefits the higher tiers in the organizational structure.

[Figure 7 about here.]

To summarize, higher organizational complexity and faster changes in production technology lead to higher GDP and wider income disparities. These disparities are, however, reduced when very large potential productivity gains reduce the aggregate productivity and constrain the distribution of profits, thereby increasing employment and demand.

3.4 Organization and wage structure

This last set of numerical simulations focuses on the joint effect of the organizational (ν) and wage (b) structure. The two structural parameters have two symmetric effects on the supply and the demand side of the economy. On the supply side, a higher number of layers (lower ν) and/or a higher wage multiplier (higher b) directly increase the firm's cost.This may also result in a higher dispersion of prices across firms through time.

On the demand side, the effect of a reduction in ν and an increase in b is twofold. First, they increase the aggregate income and its disparity between classes. Second, the increase in the number of tiers induces a stronger structural change in aggregate demand, increasing the heterogeneity in demand preferences and the range of affordable products.

Figures 8 and 9 show the effect of organization and wage structure on the average households income and, the average Atkinson index over 2,000 simulation steps, respectively. As expected, increasing the wage multiplier mechanically raises the average income across households (Figure 8). It also directly translates into higher income disparities (Figure 9).

[Figure 8 about here.]

Quite close to our expectations, a low complexity in the organization structure (high ν) leads to a lower aggregate income. This effect, however, is weaker for high values of the tier multiplier and is counterbalanced by the higher rate of shared profits that accompany low growth with no capital investment.

The effect of the tier multiplier on income disparities across classes, which exhibits a U–shaped form (Figure 9) is more complicated: extreme values of the tier multiplier correspond to high income disparities. On one side, when the multiplier is low, the large number of layers amplifies even small wage disparities among layers, generating higher inequality. On the other side, when the multiplier is high, a very small number of layers emerge and the high–income classes absorb the high rate of redistributed profits, causing large inequality even in the presence of low income disparities.

[Figure 9 about here.]

Finally, in Figure 10 we turn to the effect of organization and wage structure on GDP growth. First, the higher the organizational complexity, the higher is the GDP growth: the increase in the number of consumers directly translates into higher effective demand with a direct positive effect on growth. On the other hand, the higher the wage multiplier, the lower is the GDP growth: assuming no direct effect of wages on productivity, the increase in cost generated by high disparities in wages slows down long–run growth.

[Figure 10 about here.]

This is due to the minimum wage dynamics (Figure 18 (a) in Appendix B): the larger the discrepancies between earnings (across tiers), the lower is the minimum wage due to the lower GDP and productivity growth and the larger the difference between the commodity price and the minimum wage (Figure 18 (b) in Appendix B).[14] When large differences between the price and the minimum wage are accompanied by the high demand of large organizations' employees, growth is sustained. Otherwise, the economy experiences both high inequality and low economic growth.

To summarize, enhancing earning disparities through wage disparities and the number of layers directly increase income inequality, as one would expect. While generating inequalities, these structural conditions may also limit economic growth. Indeed, a large number of layers sustain effective demand (notwithstanding an increase of firms' cost structure); but high wage differences between layers increase the price level in the economy (and the difference between price and the minimum wage), yielding no benefits and slow economic growth.

4 Concluding remarks

A large and diverse literature has pointed to strong empirical evidence suggesting mutual effects on the relations between different dimensions of structural transformations and economic growth. We argue that the structure of production and the way in which it is organized by firms, together with the structure of demand, are the main candidates to explain the growth differences we observe across countries and within countries through time. The changes in production factors along a production function are not independent of the shifts of the function, usually referred to as the Solow residual, or technological change. Structural change encompasses much more than technological change.

In this paper we propose a model that generates structural change dynamics from the micro behavior of firms and consumers. Initial structural conditions on both sides have an impact on the changes that emerge through time. Structural changes on the two sides of the market are systematically linked and not separable; just as the rate of growth is both a source of structural change and a consequence of the initial structural conditions. The crucial link between the two sides of structural change (supply and demand) is the distribution of income. On the supply side, the earning distribution depends on the way in which firms organize their production, invest, and distribute profits. On the demand side, the hierarchical structure of firms determines different income classes, which have different consumption behaviors. The distribution of income classes determines firm selection, which again rebounds on the investment strategy, growth, and organization of firms.

The model shows how economic growth stems from a cumulative causation process involving demand shifts and technological change in the capital sector. We show that

[14] As Cornia (2003) put forward, the stickiness of the minimum wage and the increasing differences with top salaries are the main determinants of the observed inequality.

structural changes in both supply and demand are necessary conditions for this process to occur. Within this context, we isolate and study the interaction between income distribution and consumption patterns on the demand side and product variety and firms' organization and technical change on the supply side. We analyze the effect of initial structural conditions, given by five structural parameters that account for (i) product variety, (ii) variety of consumption patterns, (iii) the firm's organizational complexity, (iv) the firm's wage structure, and (v) change in production technology.

Product variety plays a relevant role in the economic growth of an economy only when it is generated through time and when it is accompanied by large heterogeneity in consumer preferences. When product heterogeneity is large from the beginning, strong firm selection hinders the cumulative feedbacks that allow a take–off of GDP. The economic quasi–stagnation is also accompanied by a large inequality due to the low incentive to invest and the consequent high proportion of distributed profits. Stretching the argument a little further in a long–run growth perspective, an economy gains from diversifying once it has built an industrial base sufficient to induce a high internal demand and investment. An initial big push toward industrial diversification is not conducive to high growth.

Organizational structures that induce the division into a large number of organizational tiers, as well as large and uneven productivity gains embodied in capital goods, lead to higher GDP levels but are also responsible for higher income inequality. Unequal distribution, in turn, might have a negative feedback effect by slowing down GDP growth. Inequality is reduced as a result of very complex organizational structures and fast technological change, due to the high incentive to reinvest profits. The results show that the effect on GDP even of rapid advances in technical change can be dwarfed by very flat organizational structures. It is thus the interplay between the two that may explain the puzzle of the cyclical rate of aggregate labor productivity in the U.S. in the last half century in the presence of substantial advances in firm level productivity.

The firm's organizational and earning structures affect economic growth both via the level of aggregate demand and income disparities. Despite increasing average wages and prices, complex hierarchical structures sustain aggregate demand in the long run, inducing demand–led cumulative causation growth. Conversely, the increase in earning disparities alone has a large negative effect on both inequality (increasing inequality) and growth, due to low investments, slow productivity changes, and a sticky minimum wage.

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A Initial conditions, sensitivity and stability

A.1 Initial conditions

This Appendix discusses the basic initial settings of the simulation model and its stationarity and sensitivity to random seeds. With this exercise we aim to clear out any ambiguity on the robustness of the results discussed in Section 3. The full set of parameters and initial conditions are reported in Tables 2 and 1. The parameters that are set to empirically observable values are reported in *italics*, while the parameters further analyzed in Sections 3.2, 3.3 and 3.4 are reported in **bold**.

We run numerical simulations for a model with $f = \{1, 2, ..., 50\}$ firms in the consumers sector and $g = \{1, 2, ..., 15\}$ firms in the capital goods sector. The only initial difference across firms is in the quality of their product, randomly assigned with a uniform distribution: $i_2 \sim U[98, 102]$. All remaining firm level initial values and parameters are identical such as the initial demand, the number of hired workers to cover it, number of tiers, cost, and price. The tier multiplier (ν) and the wage multiplier (b) lie within the boundary values observed by Simon (1957), Lydall (1959), and Prescott (2003): 5 is the average ν and 2 the maximum b in Simon (1957).[15]

The capital sector firms are also initialized as homogeneous competitors with no capital in stock to sell; they are endowed with one engineer as the existing investment in R&D. The vintage produced in the beginning also has the same embedded labor productivity across firms.

On the demand side, the labor composition of final good and capital good firms defines three consumer classes: engineers employed in the R&D lab of capital firms, shop floor workers in both the final and capital good firms, and the first manager (second tier) to supervise the shop floor workers. Wages and profit shares fully contribute to the class income share and consumption level. The initial three classes differ in terms of consumption preferences with respect to product price and quality. Consumers working in the first organizational tier are almost indifferent toward quality $\left(i_2\left(\upsilon_{1,2} = \upsilon^{min} = 0.1\right)\right)$ and strictly prefer low pricing firms $(i_1(\upsilon_{1,1} = \upsilon^{max} = 0.9))$. As we move upwards in the tiers/consumption classes (as z increases), the tolerance toward price differences increases, while the tolerance toward quality differences reduces by a multiplier δ^{υ}: $\upsilon_{z+1,2} = (1 - \delta_\upsilon)\upsilon_{z,2} + \delta_\upsilon \upsilon^{max}$ and $\upsilon_{z+1,1} = (1 - \delta_\upsilon)\upsilon_{z,1} + \delta_\upsilon \upsilon^{min}$, where υ^{max} and υ^{min} are the boundaries of the possible tolerance level. With no preliminary expectation for the consumer class composed by engineers, we have drawn them randomly $(\upsilon_{0,m} \sim U(0, 1))$.[16]

Finally, all workers/consumer classes are divided in $h_z \in \{1, 2, ..., 50\}$ samples.

[Table 1 about here.]

[Table 2 about here.]

[15] The choice of b reflects the widely accepted evidence that the wage differences within firms have increased dramatically in recent years.

[16] Given the very low ratio of engineers with respect to the rest of the population in our model, the impact of their consumption choice is negligible.

A.2 Sensitivity to random effects

Although an analysis of the stability against the most relevant parameters has been performed in this paper, in this appendix we briefly show results on the model's sensitivity to different random seeds.

Unless differently specified, the results discussed in this paper average 10 simulation runs with different random seeds in order to control for random variability and make sure results do not depend on random shocks. In what follows, we show that with our model 10 simulation runs are sufficient to wash out the randomness and present a good compromise between computational effort (the time required to run each simulation) and sensitivity to random effects.

Figure 11 shows the results for the GDP growth at constant prices, obtained from 100 different runs with different random seeds, and the averages from random samples of different sizes.

[Figure 11 about here.]

The figure shows that, although the model generates exponential growth (see Figure 1), the growth pattern is cumulative but stable. This converges, on average, to a 1% rate per period. The figure also shows that if we compare averages over 100, 50, 25, or 10 runs randomly sampled, their difference is negligible. The standard deviation between the averages converges to zero when the GDP growth pattern is nonexponential and sticks to very low values even when the growth pattern becomes exponential (after period 1,300). This suggests that when these results are evaluated from 10 runs averages, they are not biased by relevant random effects.

Similarly, the Atkinson inequality index (Figure 12) shows converging values for the across runs averages and a quite small between–averages standard deviation across simulation runs.

[Figure 12 about here.]

We then show that results from averages over 10 random runs are sufficiently robust, or at least the loss in robustness with respect to an average over 100 runs with different random seeds is negligible. We concentrate again on the two main aggregate outputs used in the analysis of this paper: GDP growth and the Atkinson inequality index. In Figure (13) we draw, on the same graph, the averages of GDP growth and their confidence interval. Confidence intervals are represented by an area with different gray scales: the larger the number of random runs averaged, the lighter the color of the confidence interval area. In other words, if the average over 10 runs significantly differs from the average over 100 runs, one should see the confidence area of the 10 runs average. Otherwise, if the confidence areas of the 10 runs averages are completely covered by the lighter confidence area of the 100 runs average, we expect no significant difference.

[Figure 13 about here.]

The GDP growth Figure (13) shows that, when we compare the confidence area of an average of 100 independent random runs with the confidence areas of 10 random averages from 10 independent subsamples of runs from the same overall sample of 100, there is no difference. In Figure 13 none of the 10 average areas which lie below the 100 runs average confidence area is visible. This allows us to infer that any 10 runs average do not generate a higher random variety than a 100 runs average.

When we perform the same exercise for the Atkinson inequality index, we obtain a very similar result (Figure 14). The difference between the confidence areas is well below one standard error. Overall, we feel confident that we can perform a robust analysis of the model using averages over 10 different runs and reducing by an exponential factor the computational time needed to create averages for 100 different random seeds. The results of the sensitivity analysis thus allow us to trade off between larger sampling — noninformative — and computational time (which increases exponentially with the number of runs) and obtain robust results on the basis of the 10 runs averages.

[Figure 14 about here.]

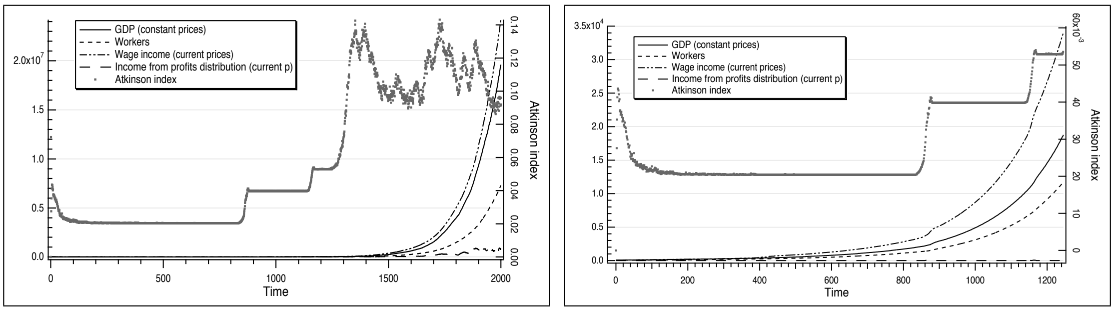
B Figures appendix

[Figure 15 about here.]

[Figure 16 about here.]

[Figure 17 about here.]

[Figure 18 about here.]



(**a**) All simulated periods (**b**) Before takeoff 'zoom'

Figure 1: ***Main macro output: GDP, population, income, and inequality***. *Aggregate results obtained running numerical simulations for 2,000 time periods with basic initialization: GDP (full series), Population of workers (short dashes), Wage (dots dash) and Profit income (long dashes), and Inequality (dots). Box (**a**) shows the results for the entire period with the takeoff and Kaldorian growth; box (**b**) shows the result for the first 1,200 time periods of demand–led growth.*

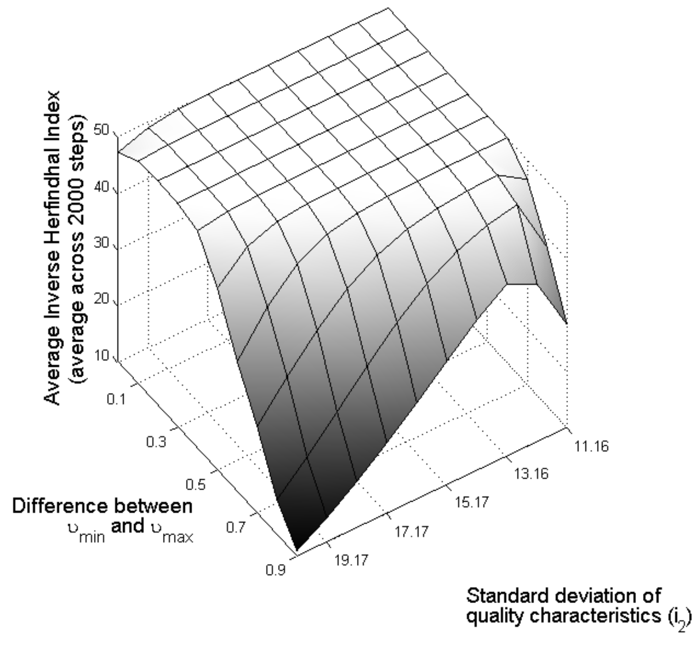


Figure 2: ***Composition of production: the effect of initial product and preferences heterogeneity on market concentration***. *The figure shows the changes in the average inverse Herfindahl Index across time periods against different values of standard deviation of the product characteristics (x-axis) as well as against changing values of the difference between the minimum and maximum level of consumer tolerance toward quality shortfalls with respect to the best firm.*

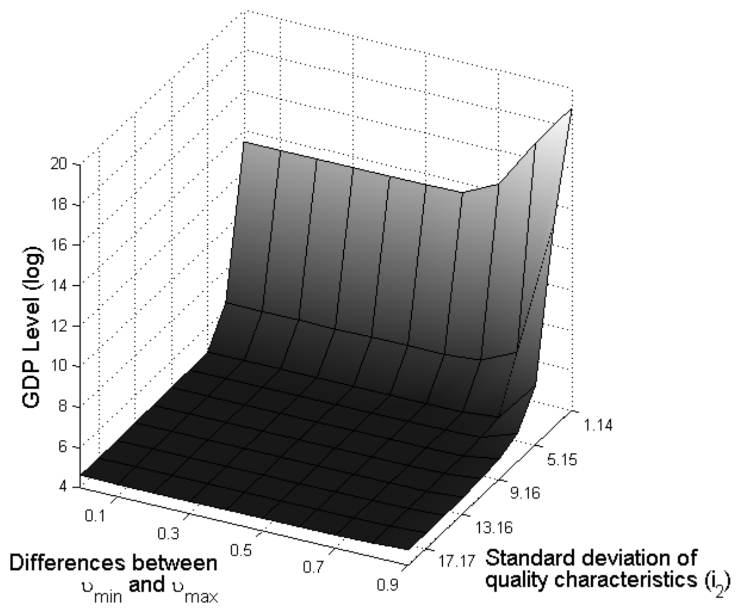


Figure 3: ***Levels of GDP (in logs) for different levels of product and preferences heterogeneity.*** *Levels of GDP in the final period of simulations are plotted against changes in the standard deviation of quality characteristics (and markup) distribution — x–axis — and changes in the difference between the minimum and maximum level of consumer tolerance for a difference in quality characteristic (or in price).*

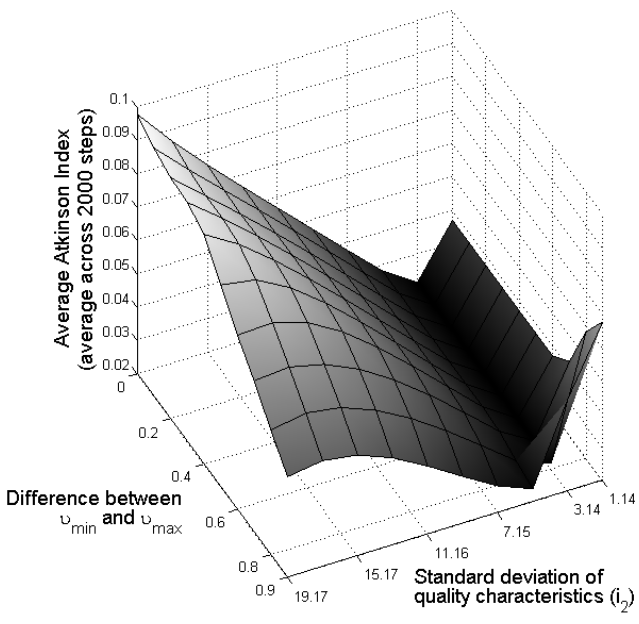


Figure 4: ***The effect of the initial composition of production and demand preferences on income inequality: the Atkinson index***

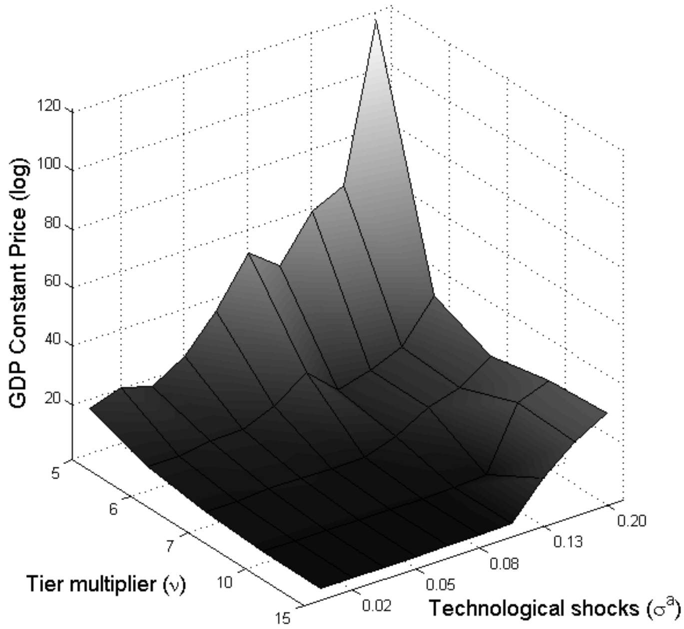


Figure 5: ***Log GDP at constant prices with changes in production and organization structure***

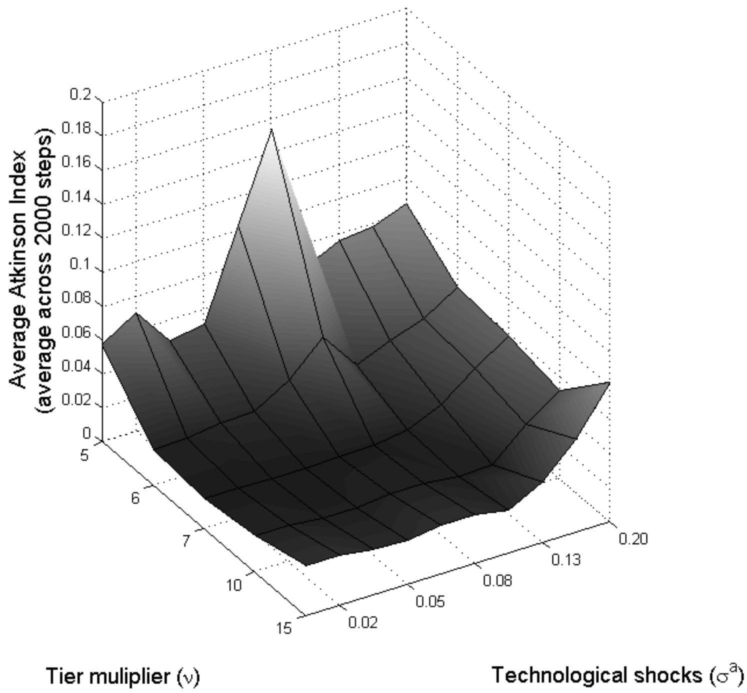


Figure 6: ***Atkinson index with changes in production structure***

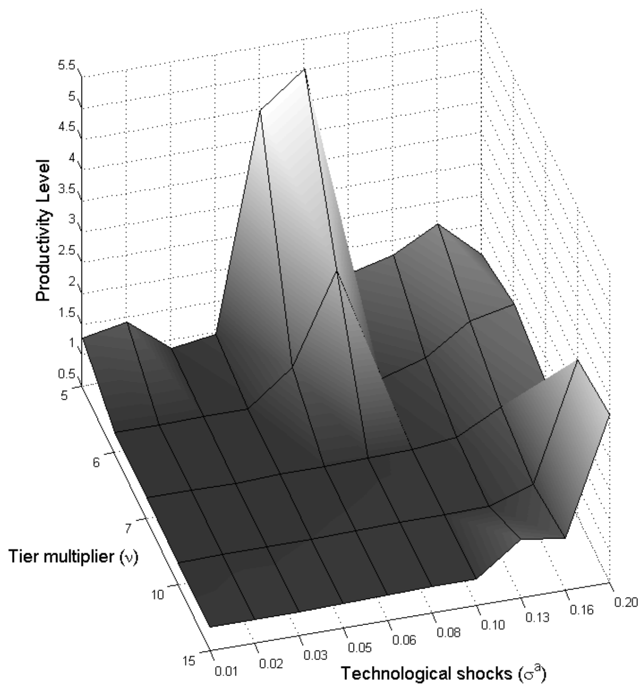


Figure 7: ***Productivity levels with changes in production structure***

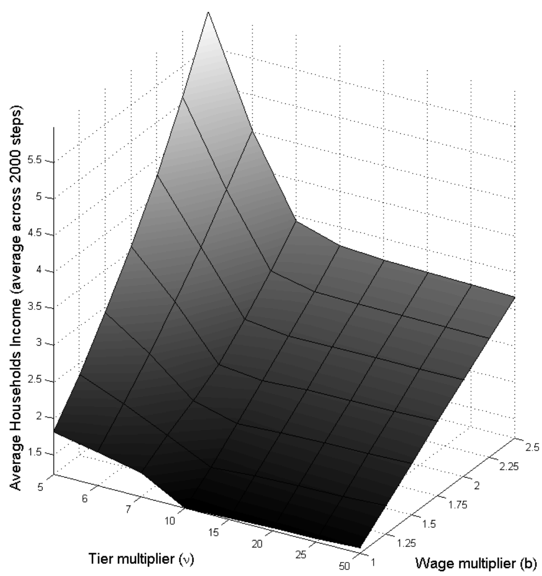


Figure 8: ***Average households income with organizational changes***

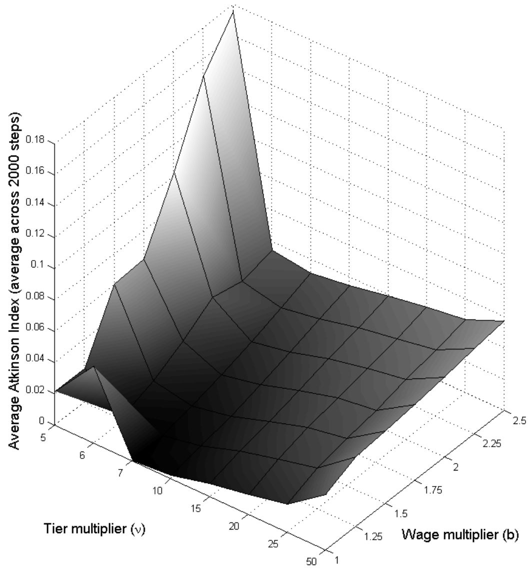


Figure 9: ***Atkinson index with organizational changes***

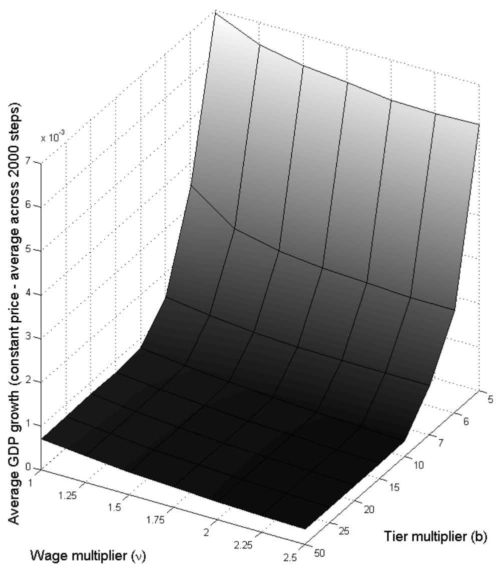


Figure 10: ***Average GDP (constant prices) growth with organizational changes***

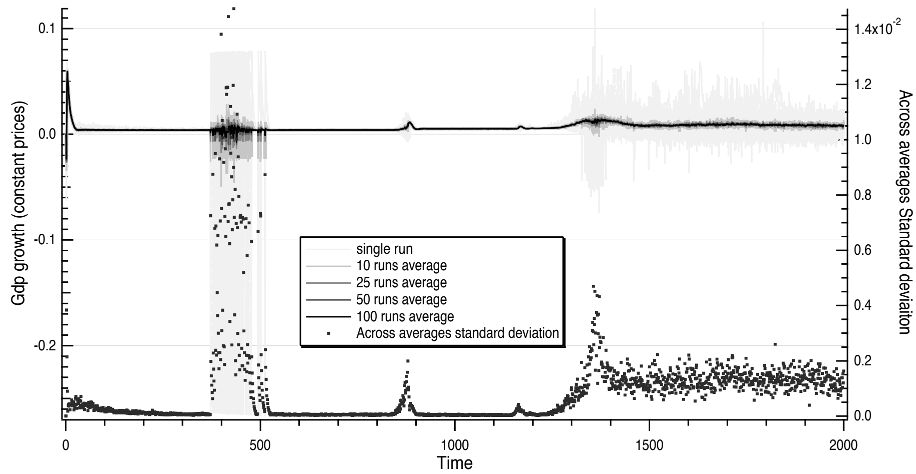


Figure 11: ***GDP growth at constant prices: 100 runs and averages***. *The light series represent the GDP growth results for 100 runs with different random seeds (left y–axis). The darker series represent averages from different samples of different sizes, all converging to the same value. Finally, dots report the inter–averages standard deviation (right y–axis).*

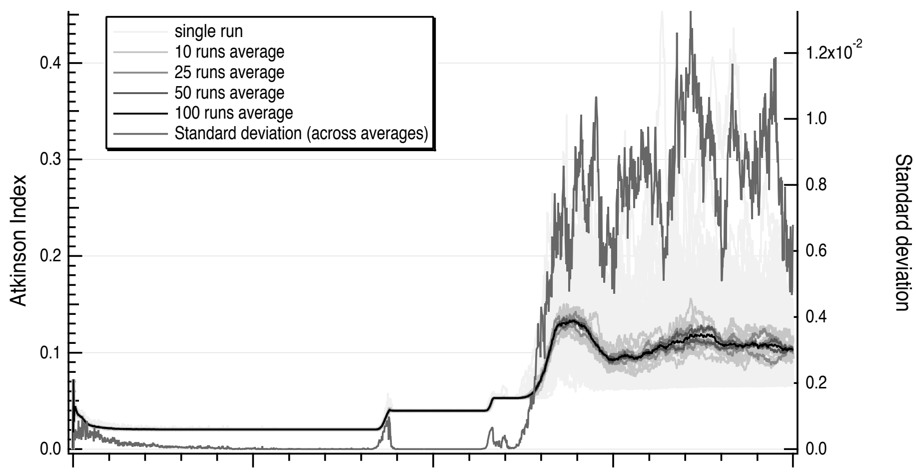


Figure 12: ***Atkinson inequality index: 100 runs and averages***. *The light series represent the results for 100 runs with different random seeds (left y–axis). The darker series represent averages from different samples of different sizes, all converging to the same value (left y–axis). Finally, dots report the inter–averages standard deviation (right y–axis).*

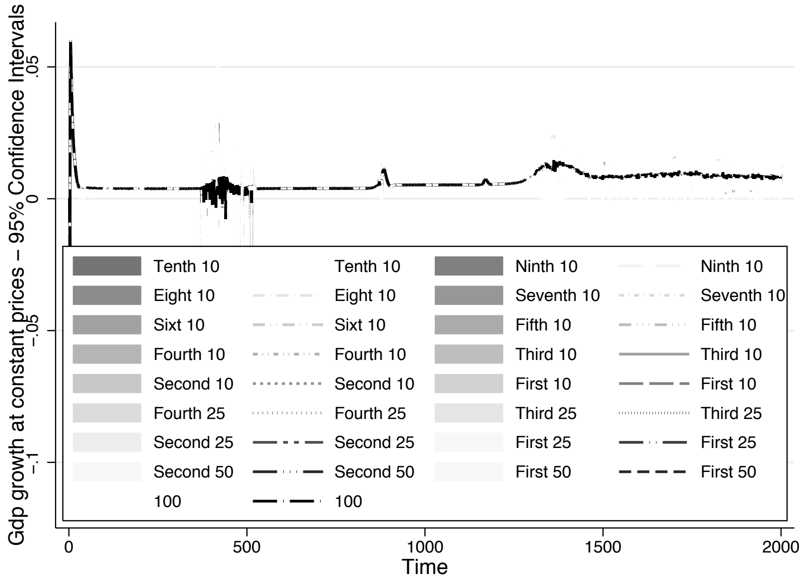


Figure 13: ***GDP growth at constant prices: averages and confidence intervals***. *The figure shows the confidence areas of the different averages (over samples of 100, 50, 25, and 10 runs) superimposed one over the other, starting from 10 runs averages. The gray scale goes from dark gray for 10 runs averages to white for the 100 runs averages. The figure shows that no section of the 10 runs confidence area exceeds the 100 runs confidence area.*

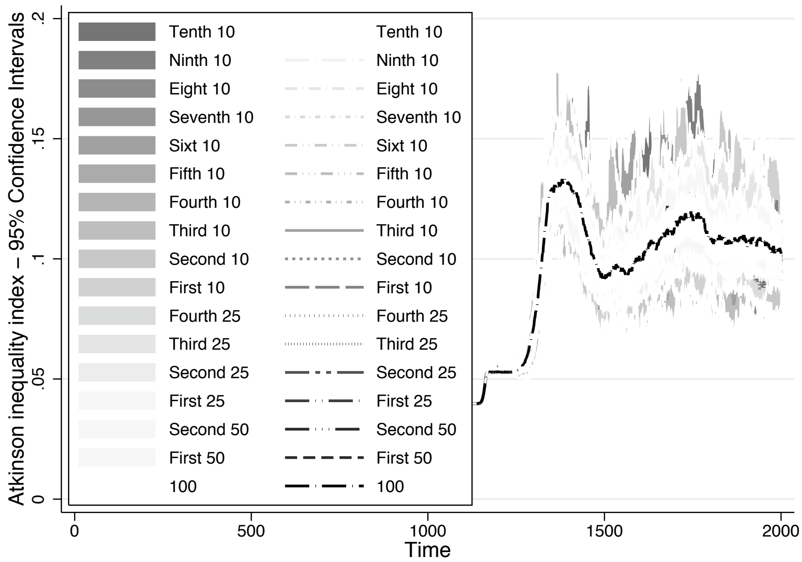
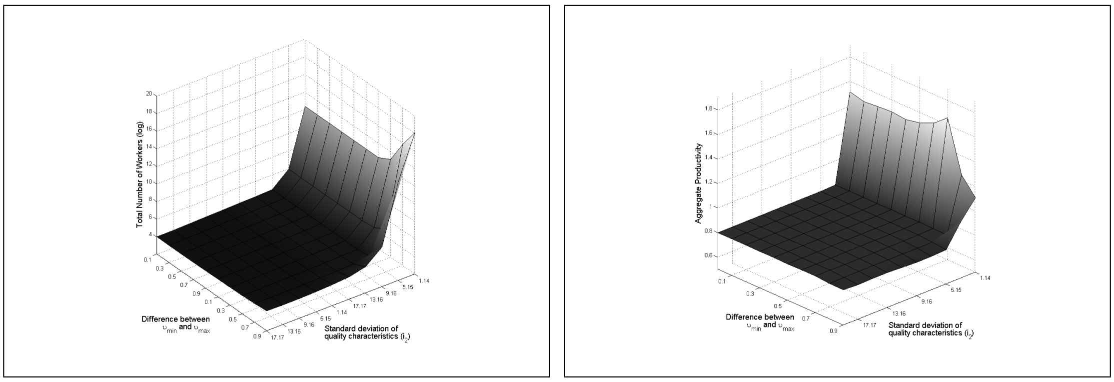
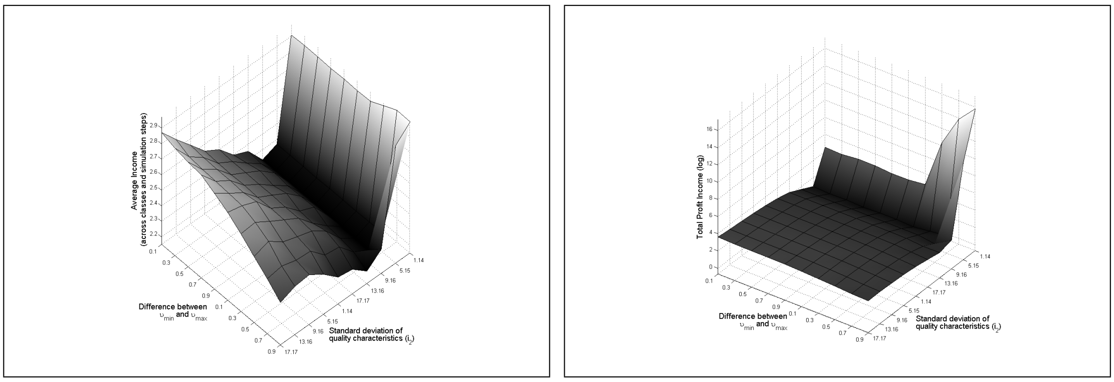


Figure 14: ***Atkinson inequality index: averages and confidence intervals***. *The figure shows the confidence areas of the different averages (over samples of 100, 50, 25, and 10 runs) superimposed one over the other, starting from 10 runs averages. The gray scale goes from dark gray for 10 runs averages to white for the 100 runs averages. The figure then shows that very small sections of the 10 runs confidence area exceed the 100 runs confidence area, amounting to a very small difference between the confidence areas of the different averages.*



(**a**) Number of workers (**b**) Aggregate productivity

Figure 15: ***Composition of production: the effect of initial product and preferences heterogeneity on employment and aggregate productivity****. The figure shows the changes in the level of hired workers (**a**) and of aggregate productivity (**b**) against different values of standard deviation of the product characteristics (x-axis) and against changing values of the difference between the minimum and maximum level of consumer tolerance toward quality shortfalls with respect to the best firm.*



(**a**) Average income (across population and time) (**b**) Total income from profit shares

Figure 16: ***Composition of production: initial product and preferences heterogeneity against income and profit shares****. The figure shows the changes in the level of average income across workers and time (**a**) as well as in the level of total income from profit shares (**b**) against different values of standard deviation of the product characteristics (x-axis) as well as against changing values of the difference between the minimum and maximum level of consumer tolerance toward quality shortfalls with respect to the best firm.*

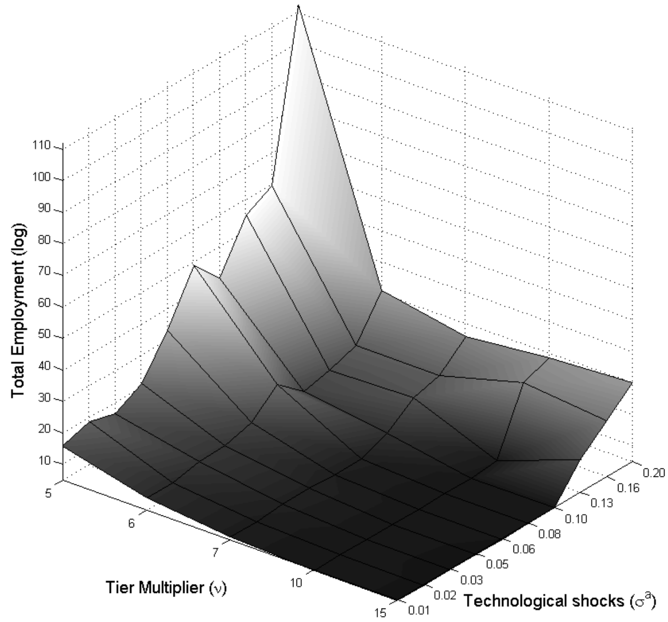
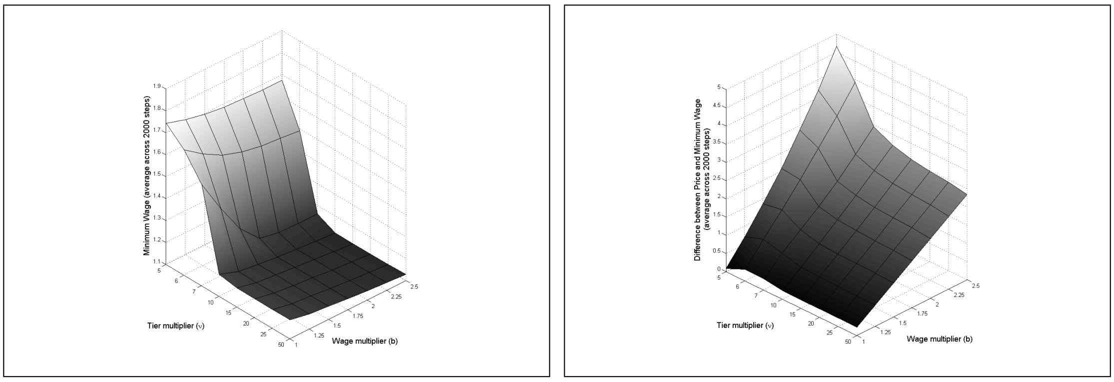


Figure 17: ***Log employment with changes in production structure***



(**a**) Minimum wage (average across time steps)

(**b**) Difference between price and minimum wage (average across time steps)

Figure 18: ***The effect of minimum wage dynamics on growth and inequality****. The figure shows the effect of the tier multiplier and the wage multiplier on the macro dynamics of the minimum wage (**a**) as well as the difference between the average price and the minimum wage (**b**). Both figures report the average values across the 2,000 simulated time steps.*

Table 1: Parameters setting: Lagged variables' initial values

Var_{t-1}	Description	Value
W_0^w	Wage income	50
W_0^ϕ	Profit income	100
w_0^m	Minimum wage	1.25152
$\bar{A}_0$	Aggregate productivity	0.18
$\bar{p}_0$	Average price	1
$\bar{A}a_0$	Moving average of aggregate productivity	0.18
S_0	Firm inventories	0
Q_0	Firm production	1
L_0	Workforce	5
p_0	Price	0.2
Y_0^e	Expected sales	1
c_0	Production cost	125
A_0	Embodied labor productivity	1
p_0^k	Capital firm price	1
L_0^{k1}	Capital firm workforce	1
z_0	Market shares	0.02
$a_{\tau=0}$	Embodied productivity (capital good)	1

Table 2: Parameters setting: Parameter values

Parameter	Description	Value[a]
ϵ^U	Wage curve unemployment elasticity	*0.1*
ϵ^P	Wage curve inflation elasticity	*0.5*
ϵ^A	Wage curve productivity elasticity	*0.1*
Ω^A	Increase in average productivity for a wage renegotiation to occur	0.05
Ω^P	Increase in average price for a wage renegotiation to occur	0.05
d	Smoothing parameter in the computation of the moving averages	*0.05*
C^L	Beveridge curve constant	*0.2*
β	Beveridge curve parameter	*6*
min_x	Minimum quality level	**98**
max_x	Maximum quality level	**102**
a^s	Speed of adaptation of sales expectations	*0.9*
$\bar{s}$	Desired ratio of inventories	*0.1*
u^l	Unused labor capacity	0.05
u^k	Unused capital capacity	0.05
$\bar{\mu}$	Markup	**0.2**
δ	Capital depreciation	0.001
$\frac{1}{B}$	Capital intensity	0.4
ϵ_L	Labor market friction (final firms)	*0.9*
ω	Minimum wage multiplier	1.11
b	Executives wage multiplier	***2***
ν	Tier multiplier	*5*
γ	Smoothing parameter	0.8
$\varsigma \cdot i_{n,m}$	Variance in the consumers' evaluation of characteristics	0.05; 0.1
δ_ς	τ inter-class multiplier	0.2
$\underline{\upsilon}$	Minimum tolerance level	***0.1***
$\overline{\upsilon}$	Maximum tolerance level	***0.9***
$\upsilon_{1,\tilde{2}}$	First–tier income class tolerance toward the quality characteristic	***0.1***
$\upsilon_{1,\tilde{1}}$	First–tier income class tolerance toward the price characteristic	***0.9***
z	Parameter innovation probability	10000
σ^a	Standard deviation productivity shock	**0.01**
ρ^k	R&D investment share	0.7
μ^k	Markup (capital firm)	0.5
ω^k	Wage multiplier in the capital sector	**1**
ϵ_M	Labor market friction (capital firms)	*0.9*
u^m	Unused labor capacity in the capital sector	0.2
$\bar{A}^k$	Labor productivity (capital firm)	1
ν^k	Tier multiplier (capital firm)	**5**
ω^E	Engineers' wage multiplier	1.5

[a]Parameters set to average observable values are in *italics*, and parameters analyzed in Section 3 are in **bold**.